FELLOWSHIP SUMMARY REPORTS

o *Name*
  Francisco Montoya Sevilla

o *The subject title and theme number of research fellowship*
  Near-Real time irrigation scheduling and crop biomass estimation through remote sensing images with high spatial and temporal resolution. (Theme 1. Managing natural capital).

o *Host institution*
  Colorado State University. Department of Civil and Environmental Engineering

o *The name of host collaborator*
  Professor José Luis Chávez Egüez

o *The dates of fellowship*
  Fellowship funded from September 18th to December 10th 2023

o I consent to my report being posted on the Co-operative Research Programme's website.

1. What were the objectives of the research project? Why is the research project important?

The main objective of this project was to improve irrigation scheduling and biomass estimations for maize crop using timely delivered high spatial and temporal resolution remote sensing-based multispectral images. For attaining this objective, the following sub-objectives were implemented: a) to develop improved maize basal crop coefficients based on a relationship of remote sensing-based vegetation index (K_{cb}-VI) and fraction of the crop intercepted photosynthetic active radiation-vegetation index (fPAR-VI); b) to generate smooth-continuous K_{cb} and fPAR curves over time derived from interpolation methods; c) to estimate the maize biomass from remote sensing images and the combined effect of potential transpiration and fPAR; d) to evaluate the proposed with near-real time field irrigation scheduling and the actual (measured) crop characteristics.

The tools and methodologies used in this research project will allow to determine the appropriate allocation of water resources to optimize/sustain biomass/yield and/or profitability of a crop of high value for Castilla-La Mancha (Spain) and the US Great Plains regions. Both places share similar problems in terms of low water availability and high irrigation requirements, whose problems are expected to increase due to global warming and greater food demand in the future. In this sense, this research fellowship has allowed:

I)   To describe properly the length of growing cycle and biophysical parameters of the maize based on VI (Normalized Difference Vegetation Index, NDVI, and Soil Adjusted Vegetation Index) data derived from micro-satellite images whose spatial resolution is 3 m and which images are captured on a daily basis.

II) To develop new relationships, mainly non-linear, between fraction of ground cover (f_c) and VI values, and K_{cb}-VI for maize when a high dense of imageries are used. The R programme was used in this study. It is a good tool to generate smooth-continuous curves for applying different interpolation methods.

III) To determine the actual crop evapotranspiration and crop transpiration using methods based on energy balance, soil water balance and sap flow, and then to derivate the crop coefficient and basal crop coefficient over two growing seasons with a crop managed under full and deficit irrigation.

IV) To compute a daily crop water stress index (CWSI), and then a daily stress coefficient which is compared to those values obtained from the CropSyst's outputs.

V)   To evaluate the CropSyst model performance in terms of crop biomass and yield when f_c evolution is derived from the VI values in order to provide a tool for making decisions.

2. Were the objectives of the fellowship achieved?
Or are they on the way to being achieved?
If not, for what reasons? (The data or research is still ongoing or being analysed; technical reasons (e.g. equipment not working, adverse weather conditions, unexpected results, etc.; other reasons?)

Objective a): Partially. The fPAR-VI relationship is still under develop since PAR data are being analysed.
Objective b): Same comment as inserted for the previous objective above.
Objective c): Partially. Crop biomass production has not yet been evaluated combining crop potential transpiration and PAR because the maize biomass production in the US Great Plains is much less affected by PAR and more by soil water deficit.
Objective d): No. Finishing the previous objectives is required to get the proper results of this objective. Moreover, we have planned to use crop information from Spain and US to evaluate this approach.

3. What were the major achievements of the fellowship? (up to three)

- The identification and development of new f_c-VI and K_{cb}-VI relationships using more than 150 multispectral images obtained from two crop growing seasons monitoring two field experiments managed under full and deficit irrigation (objectives a and b). The use of these relationships applied with a crop simulation model (objective c) will allow to identify how irrigation scheduling can be improved in a near-real time contrasting the traditional method used by irrigation advisory service regarding to that management given by the model.
- Knowledge and information assimilation through personal interactions with experts in Colorado (CO). For instance, participating in several meetings and field tours (8), as well as, attending seminars about water resources organized by Colorado State University (CSU), and by participating in the 13th United State Commision on Irrigation and Drainage (USCID) Conference held in Fort Collins, CO, as speaker. These opportunities have allowed me to interact with many researchers and technicians of my field of expertise. During the meetings, many researches showed interest in promoting future collaborations, such as the high probability of starting collaborations with the United State Deparment of Agriculture – Agricultural Resarch Service (USDA-ARS) (Fort Collins, CO) (Dr. Huihui Zhang), besides the collaboration between CSU (Prof. Chávez and Prof. Andales) and ITAP.
- Different experimental farms and laboratories were visited during the meetings, such as the USDA-ARS Limited Irrigation Research Farm (LIRF) station in Greeley (CO) and the Arkansas Valley Research Center, near Rocky Ford, CO, which is part of CSU's Agricultural Experimental Station network. This activity allowed me to familiarize myself with the research instruments used by the different research teams as well as the management of the facilities during the studies. In addition, during three field days I assisted in the operation of several micro-meteorological stations located at LIRF. The experience gained will be applied in the ITAP's field trials in Spain.

4. Will there be any follow-up work?

o *Is a publication envisaged? Will this be in a journal or a publication? When will it appear?*
Our objective is to publish at least a research paper with the new f_c-VI and K_{cb}-VI relationships obtained for maize crop managed under full and deficit irrigation. We are committed to submitting this paper by the end of 2024.

o *Is your fellowship likely to be the start of collaboration between your home institution and your host?*
ITAP and Colorado State University started the collaboration in 2016 during the fellowship of Dr. López-Urrea, and later in 2019 with the visit of Prof. Chávez at ITAP during his sabbatical year. Moreover, thanks to the contacts carried out during my fellowship, we will persue collaboration with other institutions, such as Colorado Northern Water (MSc. Altenhofen), USDA-ARS (Dr. Zhang), and Arkansas Valley Research Center (Prof. Andales and MSc. Simmons).

o *Is your research likely to result in protected intellectual property, novel products or processes?*
Yes, it is. Maybe the new f_c-VI and K_{cb}-VI relationships obtained for maize crop can be considered a novel (innovative) method or procedure.

5. How might the results of your research project be important for helping develop regional, national or international agro-food, fisheries or forestry policies and, or practices, or be beneficial for society?

Please express this in terms of environmental/food security/food safety/economic/health (human and livestock and plant) benefits, etc.

The development of precision agriculture, and the possibilities to match demands and supply it in space and time, is possibly one of the most significant advances in agriculture in recent years. Earth observation techniques have been shown to be able to accurately describe the state of the crop canopy, both in field crops and fruit orchards monitoring, through crop biophysical parameters like f_c. In this sense, results of this research project are useful for improving the maize water use estimation methods over the growing season using improved f_c-VI and K_{cb}-VI relationships obtained from the dense time series of remote sensing satellite images. This reflectance-based approach can be easily transferred to other maize producer areas with the aim to allocate the irrigation water depth at the right time and to increase the water use efficiency. In parallel, the stress coefficient estimation from a remote sensing-based approach, combined with a crop simulation model, is considered a plus for decision making by the productive sector, where the maize biomass production can be estimated managing properly the scheduling irrigation over the growing season.

6. How was this research relevant to:

o *The objectives of the CRP?*
   In accordance with the three main objectives of the CRP, this research allows:
-   To improve the irrigation water use efficiency as it is explained in the previous section.
-   To increase and predict the crop yield by using the same amount of natural resources (water and land).

o *The CRP research theme?*
   In the theme "I. Managing Natural Capital", two of the main natural resources are impacted by the results of this research project.
   On one hand, Water, where the improvement of water use efficiency aimed with this project allows to decrease in demand for natural water resources through new technologies and practices applied by the precision agriculture.
   And on the other hand, Integrated Agricultural Production Systems, where the productive optimization of the agricultural systems through combining crop modelling and remote sensing- based approaches allows facing the growing demand of agricultural products when health soil and irrigation water are constrained.

7. Satisfaction

o *Did your fellowship conform to your expectations?*
   My personal experience was better than expected. My gratitude to my host Prof. Chávez who organized a lot of meetings with other researchers and technicians, his time and patient to explain to me the field experiments and to give me support for conducting this project in a proper way. Thanks are also given to the Department of Civil and Environmental Engineering to provide me a nice office in the main Engineering building.

o *Will the OECD Co-operative Research Programme fellowship increase directly or indirectly your career opportunities? Please specify.*
   Yes, it will. Holding this fellowship in a recognized foreign research institution is considered a merit for future promotions within the framework of a postdoctoral itinerary to access to the Spanish System of Science, Technology and Innovation. As examples, ANECA (Spanish accreditation and quality evaluation agency) system and the R3 Certificate (Spanish State Research Agency) consider positively this kind of fellowship in order to recognize the quality and independence of a researcher.

o *Did you encounter any practical problems?*
   No

o *Please suggest any improvements in the Fellowship Programme.*
No improvement is suggested. In my opinion, this programme is very well organized to attain practical results in a very short period of time sharing expertise between different institutions.

8. Advertising the Co-operative Research Programme

o *How did you learn about the Co-operative Research Programme?*
Through Prof. Chávez when he spent his sabbatical time in Spain in 2019.

o *What would you suggest to make it more "visible"?*
In my opinion, this programme is well positioned in different social networks, such as twitter as well as the OECD's web page.

o *Are there any issues you would like to record?*
No.